Aqueous Cleaning
for
Precision Bearings and Beryllium

by

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ABSTRACT

The Aerospace Guidance and Metrology Center located at Newark Air Force Base in the state of Ohio, U.S.A., repairs inertial navigation and guidance equipment for the United States Air Force. The Center repairs thousands of the delicate, sophisticated electromechanical devices each year. The critical tolerances of many of the moving parts and other considerations mandate extensive "precision" cleaning as well as general cleaning during the repair process. Among the parts requiring cleaning are precision instrument bearings and assemblies containing beryllium. The principal solvents used for this cleaning have been **1,1,2-Trichloro** 1,2,2-trifluoroethane **(CFC-113)** and **1,1,1-Trichloroethane** (MCF). The Center has begun modifying its many cleaning processes to use known alternatives for these solvents. Principal among these alternatives are aqueous processes using biodegradable detergents and deionized water. All of the Center's precision instrument bearing cleaning is now done with an aqueous process. Considerable testing and evaluation are nearing completion which indicate that aqueous processes will be used to precision clean beryllium parts with many improvements over the solvent based methods.

INTRODUCTION

The Aerospace Guidance and Metrology Center is located in the state of Ohio, U.S.A., at the Newark Air Force Base. It is a repair center in the U.S. Air Force Logistics Command.

The Center has two primary missions. The first is the repair of inertial guidance and navigation systems and components used by most missiles and aircraft in the U.S. Air Force inventory. The inertial systems and components of several foreign countries are also repaired at the Center. The second mission is the management of the U.S. Air Force Single Integrated Metrology and Calibration Program worldwide.

The Center is comprised of, for the most part, one large building covering approximately fifteen acres. Within this building are a large number of smaller structures totalling over 294,000 square feet of floor space. These structures have strictly controlled environments and contain a vast array of complex repair operations.

The sophisticated electromechanical devices that form the nucleus of inertial systems are extremely susceptible to minute contamination. Particles five microns or less in size can cause a system to fail. As a result, great care must be taken to assure a clean repair environment. Of course, during the repair process it is necessary to carefully clean the parts being assembled.

The Center's industrial processes require extensive use of solvents to meet these cleaning needs and for other specific purposes. Among the solvents used are CFC-113, and 1,1,1-Trichloroethane (MCI?). Prior to 1989, the Center used over 1.5 million pounds of CFC-113 annually; less than five hundred thousand pounds was used in 1990

Once used, CFC-113, like many of the solvents, is considered a hazardous waste. The Center reprocesses most of the CFC-113 it uses to virgin quality through a sophisticated distillation system, but a significant portion is lost through evaporation and hazardous waste disposal.

CFC-113, in addition to being a hazardous waste, is a serious threat to the atmosphere. Its impact on the ozone layer has generated action to curb its production and use worldwide.

CFC-113 now costs the Center $2.40 per pound ($31.44 per gallon). This is 400% of the cost just two years ago ($0.60 per pound). In addition, the cost of recovery of vapors from the Center's industrial processes, the cost of hazardous waste disposal, and the cost of reprocessing used CFC-113 contribute to the total cost of its use. The cost of using CFC-113, the threat of even higher cost resulting from special taxes and reduced availability in the future, and environmental issues have caused the Center to take an aggressive role in finding alternatives for this and other hazardous solvents.

For the past three years, Center personnel have been engaged in an intensive evaluation of equipment, techniques and processes to identify suitable alternatives for a variety of solvent uses.

The Center's repair processes, as mentioned above, require extensive cleaning. The overwhelming majority of the CFC-113 and MCF used at the Center is used in these cleaning activities. The solvents are used in a wide variety of different types of cleaning operations. These can be summarized as flushing, bench, vapor decreasing,

ultrasonic, and impingement spray booth operations. Flushing operations involve the flowing of solvent through the assembly or system being cleaned for a defined period of time. Bench operations encompass all manual cleaning activities accomplished by a repair technician at a work station using solvent for spot cleaning.

The Center has done extensive work testing aqueous processes as alternatives for ozone depleting solvents in the critical, or precision, cleaning of metal parts and assemblies of various compositions. The term "precision" cleaning, as used at the center, encompasses the removal of particles 10 microns or less in diameter, the preparation of surfaces for ensuing processes where the quality of the ensuing process is dependent on the cleanliness of the surface, where wear between moving parts is a concern, and other special concerns involving "cleanliness".

This work has proven beyond any doubt that aqueous processes are, indeed, suitable for precision cleaning of parts and assemblies consisting of metals, epoxies, plastics, and other materials.

THE CENTER'S AQUEOUS PROCESSES AND PARAMETERS

Many lessons were learned as a result of the thoroughness required to verify that the aqueous processes were suitable as substitutes for ozone depleting solvent based processes and, subsequently, *'proving" to management that this was the case. These lessons have caused the Center to not only consider the use of aqueous processes as its principal alternative for ozone depleting solvents, but also to change the basic philosophy of cleaning in its operations.

Prior to the aqueous process investigation, each technician at the Center did his own cleaning for the parts he was working with in the area where he was doing the work. This included all precision cleaning as well as all non-precision, or general, cleaning. Over many years with hundreds of technicians performing their own cleaning, as many different cleaning "techniques" developed as there were technicians. Such a situation is extremely difficult to control for consistency and uniform quality.

Precision cleaning using aqueous processes is being done in a Precision Cleaning Center. The Cleaning Center concept provides several positive improvements to the repair operations. Of course, since fewer cleaning locations will be involved, it minimizes the expense involved in providing the equipment and facilities required for converting to aqueous based precision cleaning. It was ***learned*** early in the Center's efforts that the aqueous process worked extremely well for precision cleaning, but only if the various elements in the entire process were closely controlled; the Cleaning Center concept makes this much easier to monitor. Also significant

is the fact that a smaller number of people will be doing the cleaning. This permits a significantly higher degree of quality control in the operation; the cleaning is uniform and consistent. Long term benefits in the reliability of the repaired items are expected to result from this change in concept.

One Precision Cleaning Center has been put into operation and another is planned to go into operation in early 1992. Others will follow. The Cleaning Center concept is still evolving and improvements are being added as they are developed.

The present Cleaning Center is situated in an environment that is maintained to better than a Class 10,000 Clean Room particle count. (A Class 10,000 Clean Room is defined as having less than 10,000 particles which are 0.5 microns in diameter or larger per cubic foot.)

The flooring is an elevated platform composed of two foot square panels that are static electricity dissipative. The technicians wear static electricity dissipative shoes which are put on when entering the Cleaning Center and removed when leaving it. To qualify as static electricity dissipative, the floor and the shoes must have a resistance to ground in the range of 1 to 1,000 megohms. The combination of static dissipative flooring and shoes reduces the incidence of electrostatic charges on the technicians, and, as a result, the effect of electrostatic fields is reduced as a mechanism for recontaminating the parts which have been cleaned.

The Cleaning Center is supplied with deionized water for all of its cleaning operations. The deionized water is maintained to a minimum resistivity of 15 megohms. The quality of the water is critical to the process. The Center's research found that when the water fell below 10 megohms resistivity, the parts being cleaned showed signs of corrosion, stains, and tarnish. These problems were not exhibited when the water resistivity was above 10 megohms.

A low volume, rapid recovery hot water system heats the deionized water to 155 plus or minus 5 degrees Fahrenheit for use in the Cleaning Center. The water is filtered through 0.2 micron absolute filters before use.

The principal cleaning device in the Cleaning Center is a self contained cleaning system that cleans with ultrasonic energy using biodegradable detergents and water in a cylindrical cleaning chamber. The ultrasonic cleaning action is produced via cavitation by a cylindrical space-laminated magnetostrictive nickel design transducer which forms the cleaning chamber. The ultrasonic cleaner operates nominally at a frequency of 20 kHz with a uniform power intensity of 400 watts per gallon. The cylindrical cleaning chamber is 10 inches in diameter and 14 inches deep. Adjustable timers

control wash and rinse cycles. A solution of pure water and detergent from one of two holding tanks is pumped into the cleaning chamber to begin the wash cycle. The solutions in the two holding tanks are continuously filtered through 0.5 micron absolute filters and are maintained according to the detergent used at temperatures that range between 150 and 165 degrees Fahrenheit.. When the wash cycle is complete, the detergent and water are drained back to the holding tank. The detergent solutions are reused until the solutions reach an unacceptable level of non-particulate contamination as defined by the Center's Physical Sciences Laboratory. Deionized water is passed over the parts during the rinse cycle to flush away detergent and loosened particles. The ultrasonic action continues during the rinse cycle. The rinse water is discharged to the waste water system as it is used. (Two sources for ultrasonic cleaning equipment with these characteristics are MagnaSonic Systems, Inc., Xenia, Ohio, U.S.A., and Friess Equipment, Inc., Akron, Ohio, U.S.A.)

An aqueous spray booth is also located in the Cleaning Center. It contains a reservoir of heated water and detergent solution. When used, the solution is passed through a 0.2 micron filter. After use, the solution is returned to the reservoir for reuse. The spray pressure is variable between 0 and 200 psig, but pressures in the range of 40 to 60 psig have proven adequate for processes evaluated to date. After spraying with the solution of water and detergent, the technician rinses with heated deionized water. The spray booth with specially designed nozzles permits precleaning of recessed screw holes and other irregularities in a part's geometry prior to final cleaning in the ultrasonic cleaning equipment.

The parts are removed from the cleaner and are placed in a Class 100 laminar flow booth. (Air through a Class 100 laminar flow booth has less than 100 particles 0.5 microns in diameter or larger per cubic foot.) In the laminar flow booth, the parts are blown dry with dry, heated nitrogen. The nitrogen is filtered through a 0.2 micron filter and passed through a nuclear ionizing element to neutralize any electrostatic charge in the nitrogen or on the surfaces it comes in contact with. The parts are then transferred to a vacuum oven where they are completely dried. The vacuum oven is operated at a nominal 160 degrees Fahrenheit and a vacuum of 25 plus or minus 5 inches of mercury. The drying time varies from one to three hours dependent upon the construction and geometry of the parts being dried. After drying, the parts are placed in a second Class 100 laminar flow booth where they are prepared for shipment to their next point of use.

The Center has conducted testing and evaluation of various parts and assemblies consisting of a broad range of materials including copper, beryllium, jewels , various epoxies and plastics, and alloys of iron and aluminum. The Center's evaluation of the aqueous process using the ultrasonic cleaner has demonstrated conclusively on the parts and

assemblies tested to date that with the proper quality of deionized rinse water, proper water temperature, proper filtering of rinse water and detergent solutions, proper timing of wash and rinse cycles, proper selection of detergent? and proper orientation and loading of parts in the ultrasonic cleaning chamber, no degradation, either chemical or metallurgical, results in either the near or long term.

Several ozone depleting solvent based cleaning processes for gyroscopes have been successfully changed to aqueous cleaning at the Center. The gyroscope parts cleaned with the aqueous process include gimbal rings, float shell halves, fill tubes, end bell covers, and gaskets. In addition, miniature precision instrument bearing assemblies from most of the inertial guidance and navigation systems repaired at the Center are now cleaned using the aqueous process.

PRECISION INSTRUMENT BEARINGS

The Center cleans as many as 1000 precision instrument bearing assemblies each month. All these assemblies are cleaned by a completely aqueous process and have been since late 1989. The bearings are cleaned either because contamination in the bearing is suspected to have caused the instrument in which it was installed to malfunction or because they were removed from an instrument during disassembly and must be cleaned to assure they do not contain any contamination generated during the disassembly process. The cleaning of the bearings is part of a refurbishment process to restore those bearings which are deemed to be physically serviceable to a condition where they can meet the necessary specifications for the particular bearing in question. A list of the bearings cleaned at the Center and their materials and physical characteristics are included in Appendix A to this paper.

Prior to cleaning, the bearings are screened by a technician. Those which have defects or other aspects which the technician deems to be undesirable or uncorrectable in the cleaning and relubrication process are discarded. The bearings which pass this initial screening are then prepared for cleaning. The dust covers, if any, are removed and cleaned separately. No retainers are removed, and the balls are not separated from the races for the cleaning process.

The bearings are placed upon a fixture "tree" that orients the bearings such that their axis of rotation is parallel to the sonics of the ultrasonic cleaner. The fixture containing the bearings is then placed in the cylindrical chamber of the ultrasonic cleaner.

The bearings are washed ultrasonically for ten minutes in a detergent solution. The principle detergent used at the Center for this purpose is Ultrakleen 1025 procured from MagnaSonic Systems, Inc.

Other detergents have been tested and work effectively in the process. Following the wash cycle, the bearings are rinsed ultrasonically for five minutes in high quality deionized water.

After rinsing, the fixture containing the bearings is carefully removed from the ultrasonic cleaner and placed in a Class 100 laminar flow booth where the bearings are blown dry with nitrogen. During the nitrogen drying process the technician is careful not to cause the bearings to spin.

After blow drying with nitrogen, the bearings are placed in clean petri dishes. The petri dishes are then placed in a vacuum oven for approximately two hours to thoroughly dry the bearings.

Following removal from the vacuum oven, the bearings are examined under a ten power microscope for defects and contamination. Following this examination, those bearings which pass are subjected to a lubrication process and a final testing process.

When the aqueous cleaning process was first considered as an alternative to the various solvents used to clean the precision instrument bearing assemblies, there were concerns. They included the following. Would corrosion of the bearings increase? Would any damage be caused by the cleaning process and the ultrasonic action? Would the cleanliness that could be obtained equal or exceed that which was obtained by the solvent based process? Testing was conducted to evaluate these concerns.

During the testing phase, various size bearing assemblies cleaned in the aqueous process were disassembled so that their metal parts could be examined and analyzed on a scanning electron microscope (SEM) built by Applied Research Lab. The bearings were checked for residue and any damage done during the cleaning process. All parts that were examined with the SEM showed no residue left (sodium or phosphate) and evidenced no damage done during the cleaning process. Teflon inserts were examined for expansion or shrinkage due to heat. No changes in dimensions were detected.

As a final test for the bearings cleaned with the aqueous process and then refurbished, a trace for each bearing was obtained on a running torque tester to test for bearing serviceability. The tester used for this purpose is a Model RT2C Bearing Torque Tester made by Miniature Precision Bearings Corporation. The bearings were rotated both directions on the tester. The magnitude and pattern of the peaks on the RT2C Tester indicate various conditions in the bearing such as poor geometry, possible retainer hangup, dirt spikes/contaminated bearing, a brinell or flat on a raceway, brinelled or potted raceway, and poor race to face parallelism within the bearing geometry. This testing indicated that the bearings cleaned with the aqueous process were not being damaged during the

ultrasonic cleaning process and that no measurable contamination remained after the cleaning. The results of the various testing satisfied the Center's personnel that the aqueous process was, indeed, an acceptable alternative to the solvent based processes.

Following implementation of the aqueous cleaning process for precision instrument bearings, the Center's technicians have observed less formation of surface corrosion than they had observed with the previous processes. Our Physical Sciences Laboratory personnel have deduced the reason for less formation of corrosion following the aqueous cleaning is that the bearings are now being cleaned more thoroughly and that fewer contaminants remain on the bearing surface to cause corrosion.

Many benefits resulted from the implementation of the aqueous cleaning process for precision instrument bearings. These benefits include reduced solvent consumption, reduced cleaning process time, improved cleanliness? reduced corrosion, reduced cost for cleaning medium, and higher yields. Yields of all the bearings passing through the refurbishment process have increased; the yield increases have ranged from 25% to 65%.

BERYLLIUM

The metal beryllium has been used extensively in inertial systems and components because of its lightness and high strength-to-weight ratio, stiffness and good machinability. Several of the systems and components repaired at the Center have beryllium components. These include aircraft as well as missile navigation and guidance systems. There is a common belief, however, in many circles that beryllium cannot be cleaned with aqueous processes because of associated corrosion potential.

In 1965 A. J. Stonehouse and W. W. Beaver of the Brush Beryllium Company, Cleveland, Ohio, published an article titled "Beryllium Corrosion and how to prevent it" in Volume 4, No. 1, of Materials Protection, an official publication of the National Association of Corrosion Engineers. In their article they state "In low temperature, high purity water, there is little or no corrosion problem with beryllium." They identify "low temperature water" as being below 210 degrees Fahrenheit. They further describe testing they had done on "unprotected beryllium" using water and detergent as a cleaning medium: "Cleaning followed by adequate rinsing and drying will increase the metal's resistance to corrosion." Storehouse and Beaver are also quick to point out "..beryllium's performance in tap water is poor. .." citing that small concentrations of several ions including ions of chloride and sulfate will cause pitting and other evidences of corrosion.

In 1990, with this information as a starting point, the Center-s engineers began testing the high purity aqueous cleaning processes they had developed on beryllium. The results of this testing have been exciting. Beryllium components from two major systems have been extensively tested and aqueous processes have been developed which perform splendidly.

As has been the case in all the aqueous processes developed at the Center, the processes developed to clean *beryllium* required tailoring. Fixturing was made to align some parts in a particular orientation in the ultrasonic field of the cleaner. The detergent found to be effective at removing the contaminants of the parts tested to date with the least effect on the beryllium itself is Liquid Detergent Number 2 manufactured by Oakite Products, Inc., Berkeley Heights, New Jersey. This detergent is used in many of the Center's aqueous processes.

An interesting illustration of the tailoring required to adapt aqueous processes to the particular cleaning requirement at hand occurred with the beryllium end housing of a component used in the Minuteman missile guidance system. The end housing had small diameter, dead end, threaded holes around its circumference. The old process for cleaning the end housing with solvents required many iterations of the cleaning steps to remove all traces of oil from these particular holes. It was found that the same thing occurred with the aqueous process when it was first tried, i.e. the ultrasonic cleaning system did not adequately clean the inside of the holes. The engineers then made a small nozzle to fit inside the hole; the nozzle was attached to an aqueous spray system in a booth where the technician can quickly use water and detergent to clean each hole manually and, using the same nozzle, rinse with heated deionized water. Following the spray operation, the end housing is final cleaned in the ultrasonic cleaner. Significantly fewer ultrasonic cycles are required to attain the same level of contamination removal as the current process.

The beryllium assemblies tested to date include, in addition to beryllium, stainless steel, gold, an epoxy resin potting compound, aluminum oxide, etc. With these assemblies and with pure beryllium parts, the results of the aqueous processes are excellent. The parts and assemblies can be cleaned cleaner than they were cleaned using solvents. They can be cleaned faster and, most importantly, they can be cleaned without any chemical or metallurgical damage. No corrosion results, and integral aspects of assemblies such as epoxy seals are not damaged.

The testing and evaluation of aqueous cleaning for beryllium parts and assemblies is nearing completion at the Center. Converting the present solvent based cleaning processes for beryllium to aqueous

processes is expected to take place in early 1992 for certain Minuteman missile guidance system components and for parts of the Carousel inertial navigation system.

CONCLUSION

Despite commonly encountered rhetoric to the contrary, precision bearings and beryllium can be effectively cleaned with aqueous processes; the Aerospace Guidance and Metrology Center is doing it and obtaining very gratifying results. With proper attention to process parameters developed through careful testing and evaluation, the Center has concluded it can clean precision bearings and beryllium with aqueous processes with no corrosion from the process or subsequent to it if the items in question are handled and stored properly. Also, faster cleaning times and better cleaning are achieved over the traditional solvent based methods.

APPENDIX A

Precision Bearings Cleaned at AGMC

The precision instrument bearings identified in this document are routinely cleaned by the Aerospace Guidance & Metrology Center (AGMC) at Newark Air Force Base in Ohio, USA as part of a refurbishment process for the bearings. The cleaning process is an aqueous process using an ultrasonic cleaner, detergent, and deionized water. All bearings are ball bearings used in various capacities in inertial guidance and navigation systems repaired at AGMC. The bearing information included was obtained from manufacturer data sheets or from the Air Force Master Item Identification Database (D043A) located at Wright Patterson AFB, Ohio.

A list of definitions for the abbreviations and terminology used is included below.

Definitions

430 SST	Type 430 Stainless Steel
440C SST	Type 440C Stainless Steel
960446	Litton specification (oil)
AISI	American Iron & Steel Institute
Cres	Corrosion Resistant Steel
Dia	diameter (inches)
HC/Cr Steel	- High Carbon Chromium Steel
IAW	in accordance with
MIL-L-####	- Military Specification Number
NSN	- National Stock Number
QQ-S-####	- Federal Specificationl/standard
Ret	Retainers
SAE	Society of Automotive Engineers
SAE 52100	- AISI E52100 (Chrome Steel)
S ep	Separators
SM####	Specification Number
SST	Stainless Steel

Note: Items with Asterisks (*) are tested on a Miniature Precision Bearings (MPB) Torque Tester (Model RT-2) after cleaning and lubrication to verify the bearings meet the required specifications.

Bearing 1:	MATERIALS	Rings - SAE 52100 Balls - SAE 52100 Retainer - Phenolic
	LUBRICANT	Mobil 28
	OUTER DIA.	.5000- .0002
	INNER DIA.	.1573- .0002
Bearing 2: *	MATERIALS	Rings - SAE 52100 Balls - SAE 52100
	LUBRICANT	MIL-L-6085A
	OUTER DIA.	.5000- .0002
	INNER DIA.	.1875- .0002
Bearing 3:	MATERIALS	Rings - SAE 52100 Balls - SAE 52100 Retainer - Phenolic (paper-based)
	LUBRICANT	Mobil 28
	OUTER DIA.	.62991.6297
	INNER DIA.	.1575/.1573
Bearing 4:	MATERIALS	Steel Corrosion Resisting Overall
	LUBRICANT	MIL-L-6085
	OUTER DIA.	.5 nominal
	INNER DIA.	.25 nominal
Bearing 5: *	MATERIALS	Rings, Balls, Ret - Steel Shields - Steel Corrosion Resisting
	LUBRICANT	MIL-L-6085
	OUTER DIA.	.375 nominal
	INNER DIA.	.125 nominal
Bearing 6: *	MATERIALS	Rings - HC/Cr STL Balls - HC/Cr STL Separator (in) - SST (out) - Teflon
	LUBRICANT	SM2049-01
	OUTER DIA.	.62481.6250
	INNER DIA.	.18731.1875
Bearing 7: *	MATERIALS	Rings , Balls - SST Sep, Shields - SST
	LUBRICANT	SM2049-01 (Mobil 7L4)
	OUTER DIA.	.5000/.4998
	INNER DIA.	.1875/.1873

Bearing 8: *	MATERIALS	Rings, Balls - SM2058 Sep, Shields, Ret Rings - SST
	LUBRICANT	SM2049-02 (Mobil 743)
	OUTER DIA.	.5000/.4998
	INNER DIA.	.1875/.1873
Bearing 9: *	MATERIALS	Rings, Balls - HC/Cr STL Sep - Teflon Shields, Ret Rings - SST
	LUBRICANT	SM2049-01
Bearing 10:	MATERIALS	Rings, Balls - 440C SST Ret - 430 SST
	LUBRICANT	Anderol L243 (SM1560)
	OUTER DIA.	.8750/.8748
	INNER DIA.	.4100/.4098
Bearing 11: *	MATERIALS	Rings, Balls - SAE 52100 Shields, Ret - Cres per QQ-S-763, series 300 or 400
	LUBRICANT	Mobil 743A
	OUTER DIA.	.6250- .0002
	INNER DIA.	.2500- .0002
Bearing 12: *	MATERIALS	Rings , Balls - SAE 52100 Retainer - Cres (type 430) Sep - Teflon Shields - Cres per QQ-S-763/766, class 302
	LUBRICANT	Mobil 743
	OUTER DIA.	.6250- .0002
	INNER DIA.	.18745- .00005
Bearing 13: *	MATERIALS	Rings , Balls - SM2058 Sep (in) - SST (out) - Teflon Shields, Ret - 302 SST
	LUBRICANT	SM2049-01
	OUTER DIA.	.62501.6248
	INNER DIA.	.1875/.1873
Bearing 14: *	MATERIALS	Steel Corrosion Resisting Overall
	LUBRICANT	MIL-L-6085
	OUTER DIA.	.5 nominal
	INNER DIA.	.1875 nominal
Bearing 15: *	MATERIALS	Rings, Balls, Sep, Shields, Ret - SST
	LUBRICANT	MIL-L-6085 (SM1827)
	OUTER DIA.	.6250/.6248

	INNER DIA.	.2500/.2498
Bearing 16: *	MATERIALS	Cres overall
	LUBRICANT	MIL-L-6085
	OUTER DIA.	.625/.6248
	INNER DIA.	.25/.2498
Bearing 17:	MATERIALS	Rings, Balls - Cres, 440C Ret - 24 ST aluminum bonded to phenolic
	LUBRICANT	MIL-L-6085
	OUTER DIA.	1.1875/1.1871
	INNER DIA.	.75/.7497
Bearing 18:	MATERIALS	Cres overall
	OUTER DIA.	.5 nominal
	INNER DIA.	.1875 nominal
Bearing 19:	MATERIALS	Steel, comp 440A overall
	LUBRICANT	Grease
	OUTER DIA.	.375/.3748
	INNER DIA.	.1295/.1293
Bearing 20:	MATERIALS	Rings, Balls - Cres, 440C Spacer - Cres springs Ret - Teflon
	LUBRICANT	IAW 960446
	OUTER DIA.	3.125/3.1245
	INNER DIA.	2.5625/2.5621
Bearing 21:	MATERIALS	Rings , Balls - Cres, 440C Sep - Teflon
	LUBRICANT	IAW 960446
	OUTER DIA.	.5/.4998
	INNER DIA.	.25/.2498
Bearing 22:	MATERIALS	Rings, Balls - Cres, 440c Sep - Teflon
	LUBRICANT	IAW 960446
	OUTER DIA.	1.3125/1.3121
	INNER DIA.	1.0625/1.0623
Bearing 23:	MATERIALS	Rings, Ball - Steel comp 440c Ret - Plastic tetraflouroethylene
	OUTER DIA.	4.5 nominal
	INNER DIA.	4.0 nominal
Bearing 24:	MATERIALS	Rings, Ball - Steel comp 440A Ret - Plastic Polytetraflouroethylene
	OUTER DIA.	2.2497/2.2494

	INNER DIA.	1.8122/1.8119
Bearing 25:	MATERIALS	Rings, Ball - Steel, comp 440A Ret - Plastic Polytetraflouroethylene
	OUTER DIA.	2.25/2.2496
	INNER DIA.	1.8125/1.8121
Bearing 26:	MATERIALS	Rings, Balls - Steel comp 440A
	OUTER DIA.	2.2498 nominal
	INNER DIA.	1.8123/1.8119
Bearing 27:	MATERIALS	Rings, Ball - Steel Comp 52100 Ret - Plastic Polytetraflouroethylene
	LUBRICANT	MIL-L-6085
	OUTER DIA.	4.0/3.9997
	INNER DIA.	3.5/3.49975
Bearing 28:	MATERIALS	Rings, Ball - 52100 Steel
	OUTER DIA.	.5 nominal
	INNER DIA.	.1565- .0005
Bearing 29:	MATERIALS	Rings - 52100 Steel
	OUTER DIA.	.5 nominal
	INNER DIA.	.1562/.1560